

*Citation for published version:*

Savoikar, P, Orr, J & Borkar, S 2015, Advanced tests for durability studies of concrete with plastic waste. in *UKIERI Concrete Congress Concrete Research Driving Profit and Sustainability*.

*Publication date:*  
2015

*Document Version*  
Early version, also known as pre-print

[Link to publication](#)

**University of Bath**

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# ADVANCED TESTS FOR DURABILITY STUDIES OF CONCRETE WITH PLASTIC WASTE

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**ABSTRACT.** This paper reviews the literature available on utilisation of waste materials in concrete and its effect on the strength and behaviour of concrete. Considering the effect of over-exploitation of natural sand from river beds for ever increasing concrete production, alternatives to natural sand are being explored. One such alternative discussed in this paper is shredded/pulverised recycled plastic waste which has been used as a partial replacement for natural sand (replacements up to 20-40 % by volume). The option of partially replacing ordinary Portland cement with ground granulated blast furnace slag is also explored. Concrete produced with plastic waste is expected to give lower values of 28-days characteristic strength and at the same time there can be questions regarding its long term durability and behaviour during fire. This paper explores various tests that can be performed to determine long term durability, chloride ingress resistance and fire performance.

**Keywords:** Accelerated durability, plastic waste, GGBS, Fire test, Carbonation.

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## INTRODUCTION

Concrete is a dense matrix composed of cement, sand, coarse aggregates and water. In India there is growth in infrastructure projects for which consumption of concrete will be very high. Production of cement and concrete, both require consumption of natural resources/raw materials. Environmentalists have raised an alarm on indiscriminate mining of natural sand from rivers since it may create imbalance in the ecosystem. This is particularly important in Goa, as discussed below.

Concrete is used extensively all over the world and is the most widely used material in the world after water. The global cement industry is growing with present production approaching 4.18 Gt in 2014 [1].

Considering the above facts, several attempts have been made worldwide to find suitable partial replacement for each of the ingredient of concrete viz. cement, sand and coarse aggregate. Production of cement requires calcination of limestone and clay at very high temperature using natural fuel. This process releases about 1 tonne of CO<sub>2</sub> for every tonne of cement produced. All these factors lead to use of cementitious materials either during manufacture of cement or in the production of concrete as partial replacement for ordinary Portland cement. Attempts were made to utilise industrial bye-products/waste products such as fly ash and ground granulated blast furnace slag (GGBS). After successful research works blended cements using GGBS or fly ash were produced and utilised. GGBS has already been used widely as partial replacement for ordinary Portland cement (OPC).

Subsequently, attempts were made to find suitable replacements for other important ingredients of concrete like sand and coarse aggregate but without much compromise on quality of concrete produced. These partial replacements for sand include materials like crushed sand, plastic waste, foundry sand, glass powder. For coarse aggregates replacements include recycled plastic aggregates and construction and demolition waste. A detailed account of this research is given in the literature survey below.

## LITERATURE REVIEW

Shredded plastic waste of different types such as PET bottle waste, polythene bags waste and injection moulded plastic waste has been tried as partial replacement for fine aggregates to the extent of 1%, 5% and 10% [2]. It was observed that there was reduction in compressive strength when shredded plastic waste was used. However, the decrease in strength was more in the case of injection moulded plastic waste while for polythene bag waste the decrease in strength was least. PET bottle were also used as partial replacement for fine aggregate in concrete to the extent of 5%. It was reported that the increase in strength from 28 days to 365 days similar to ordinary concrete while there was slight decrease in strength when compared with ordinary concrete. It was observed that the stress - strain curves for PET concrete depicts same trend as that of ordinary concrete [3].

Sand replacement to the extent from 2% to 100% was tried with granulated PET aggregates of up to 5mm size in concrete [4]. It was reported that the compressive strength of concrete is affected when such replacements are made above 50%. Reductions in compressive strength were reported when PET light weight aggregates were used in concrete [5]. Shredded waste Poly-ethylene Terephthalate (PET) bottle granules has been tried as lightweight aggregates of sizes between 0 to 4mm, in mortar [6]. Results revealed that mortars containing only PET

aggregate, mortar containing PET and sand aggregate, and mortars modified with slag as cement replacement can be considered as structural lightweight concretes.

Ismail and Al-Hashmi [7] tested waste plastic as a partial replacement for up to 20% of sand. The waste plastic had a broad distribution of sizes, with length varying from 0.15–12 mm and width of 0.15–4 mm. Cubes cast from such concrete were tested for compressive strength and dry density tests while prisms cast were tested for flexural strength and toughness indices tests at various stages of curing for 3, 7, 14, and 28 days. It was concluded that propagation of micro cracks is arrested by introducing waste plastic of fibriform shapes and that reusing of waste plastic as a sand-substitution aggregate in concrete helps reduce the cost of materials and solves disposal problems of these plastic wastes. Plastic fibres, to the extent of 0-3% by volume, from PET bottles has been used as reinforcements in conventional concrete [8]. It was reported that workability and the dry density of mix reduced when such fibres were used. Linear relationship was obtained between cube and cylinder strength. A more deformable failure was reported in the case of specimen made from such fibres. Structural performance of the fibre reinforced concrete was evaluated using PET and polypropylene fibres [9]. It was reported that the compressive strength and elastic modulus of such concrete decreased when fibre volume was increased. However, it was observed that the cracking due to drying shrinkage was delayed when PET fibres were used as compared to conventional concrete. Improvement in ductility of concrete was reported when fibres were used in concrete [10].

Glass reinforced plastic (GRP) waste powder had been tried in concrete to improve its compressive strength [11] with varying dosages from 5%, 15%, 30% and 50% (w/w). It was reported that compressive strength decreases with increase in GRP percentage. However, improvement in compressive strength was observed when curing period was increased which indicated that GRP can be recycled for precast works. Crushed glass have been tried as partial replacement for coarse aggregates varying from 15% to 60% [12]. It was found that slump and unit weight of concrete reduces when glass is used as partial replacement for coarse aggregates. When coarse and fine aggregates were partially replaced by the recycled glass aggregates, it was observed that slump value increases [13]. Expanded glass aggregates, manufactured from finely ground post-consumer glass with suitable expanding agent, when used in concrete, were found to be highly reactive and could activate-alkali silica reaction [14].

Rubber waste granules of 2mm in diameter and shreds having sizes of 5.5mm × 1.2mm and 10.8mm × 1.8mm has been tried in concrete. It was reported that workability improves with the rubber waste [15]. Decrease in slump was reported for the fine crumb rubber and coarse tire chips used in PCC mixtures [16]. Reduction in slump was reported for 5-10% partial replacement of fine aggregates with automobile tyre treads of particle sizes of 0.29mm and 0.59mm [17].

Tests on recycled aggregate from construction and demolition waste (CDW) and ethylene vinyl acetate (EVA) waste, in concrete as a replacement for natural coarse aggregate were conducted. The results revealed that the EVA waste and CDW can be used in production of lightweight concrete [18].

Foundry sand has also been found as suitable material in manufacture of cement, partial replacement for sand and in concrete products as well [19,20] and Bottom ash has also been tried as partial replacement for coarse as well as fine aggregates in concrete [21,22].

## CRITICAL APPRAISAL OF THE LITERATURE

The above researchers and many others have others have worked on finding suitable alternatives for cement, sand and coarse aggregates so as to reduce pressure on over exploitation of these natural resources. At the same time many other waste products/by-products from industry/agriculture or post-consumer use products have been tried as replacement for the above natural resources. The available research have shown that replacement of aggregates (coarse and fine) by these waste products has been successful partially but most of the research shows either there is reduction in strength or workability and that concrete can be utilized for non-structural works. However, the benefit accrued from safe disposal of these waste products (in concrete), which otherwise would have gone into the landfills or open dumps which would have been cause environmental pollution, cannot be overlooked.

Ground granulated blast furnace slag (GGBS) and fly ash are two important industrial waste products which has been widely used in manufacture of blended cements and also as partial replacement for ordinary Portland cement in ready mixed concrete. Their adaptability, effectiveness in developing strength and durability has already been establish are forming part of almost every load of concrete being produced worldwide.

In most of the above researches, use of waste product has shown that slump/workability has been affected along with the strength. Secondly, the concrete which has been thus made is not suitable for structural works. Also, the long term durability studies, carbonation effect, fire resistance which are very important properties, have been seldom studied.

In the view of above context, the present work relates to development of structural concrete by partially replacing natural sand with plastic waste (composed of shredded/pulverized polythene bags waste, shown in Figure 1) and also studying the long term effects of plastic waste in concrete as regards its effect on long term durability, carbonation effects and fire resistance.



Figure 1 Shredded/pulverised Polythene carry bags waste used in present study

## STUDIES ON DEVELOPMENT OF STRUCTURAL CONCRETE WITH PLASTIC WASTE AT GOA & UK

After pilot studies on utilisation of various forms of plastic waste at Government Polytechnic, Bicholim-Goa [2], the present study started simultaneously at Goa and at University of Bath, UK under the scheme UKIERI, funded by British Council, in the second half of 2014. It aims to develop a structural concrete with plastic waste as a partial replacement for natural sand. The topic gains importance in Goan context since there was over exploitation of natural sand from rivers, which were the only sources of sand in Goa, to support the ever growing construction industry in the State and subsequent ban on over exploitation of natural sand. So, the plastic waste was looked upon as a suitable partial replacement, with the above limitation as reported in various researches.

In the present study, to reduce the effect of plastic waste on workability, a suitable chemical admixture has been used to enhance the workability. The expertise and sophisticated machinery available at the University of Bath is being used to assess the long term durability, carbonation effects and fire resistance/behaviour of the concrete being developed.

### Material used

In the present study, ordinary Portland cement has been used in combination with GGBS as partial replacement to it. Up to 50% replacement of ordinary Portland cement with GGBS is being tried. Coarse aggregates of size 10mm and 20mm are used while natural sand both coarse and fine is used. Standard glinium/naptha based admixture (1% by weight is used). Plastic waste used is shown in Figure 1. Plastic waste replacement up to 40% is tried.

### Testing work

As the initial part of testing work, routine tests on various ingredients on concrete (above materials used) were done as per the respective Indian Standards. Fine aggregates were tested as per IS: 383-1970 for grading limits for fine aggregates. It was observed that natural sand falls in Zone II while the pulverized polythene bags waste falls in zone I. The average dry loose bulk density of plastic waste was  $315 \text{ kg/m}^3$  and its specific gravity was 1.43. Mix design was done as per IS:10262-2009 for M25 mix with water:cement ratio of 0.45. A typical mix design considering water absorption of coarse and fine aggregates and necessary adjustments in ingredients for M25 mix is shown in Table 1.

Table 1 Typical mix design (per  $\text{m}^3$ ) for M25 grade concrete with 20% plastic waste

Cement 58%	GGBS 42%	Fine Sand	Coarse Sand	Coarse Aggregate		Water	Admixture	Plastic 20%
				10mm	20mm			
kg	kg	kg	kg	kg	kg	litre	kg	kg
197	143	381	550	450	614	144	3.4	21

### Slump, Compressive strength and flexural strength results

Typical results of the various trial mixes (Mix 1 is a control mix while Mix 2 and 3 are with 20% plastic waste while Mix 4 and Mix 5 are with 40% plastic waste) are shown in Table 2. The target mean compressive strength of the mix was 33.25 N/mm<sup>2</sup>. The results show that there is marginal decrease in slump when plastic waste was used, whereas there is considerable decrease in the 28 days compressive strength of the concrete specimen with varying plastic waste.

Table 2 Slump, Compressive Strength and Flexural Strength results for M25 grade

Trial mix	Cement:GGBS	Plastic %	Slump (mm)	Strength results	
				28 day compression N/mm <sup>2</sup>	Flexural (N/mm <sup>2</sup> )
1	58:42	0	147	34.2	5.62
2	58:42	20	130	27.5	5.17
3	58:42	20	140	32.0	5.40
4	58:42	40	120	26.8	4.80
5	50:50	40	122	21.3	4.63

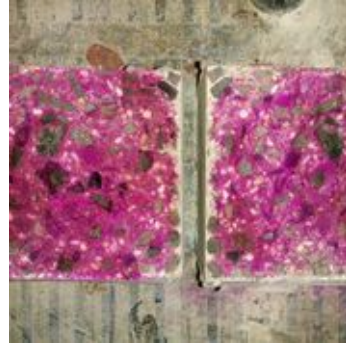
### DURABILITY TESTING OF CONCRETE SPECIMENS

#### Accelerated Carbonation studies

Accelerated carbonation studies are performed as per BS 1881-210:2013 by subjecting the concrete cubes/prisms to much higher levels of carbon dioxide than the atmospheric one with relative humidity conducive to a maximum rate of carbonation. This test requires a period of 112 days which consists of specimen age of 28 days, subjected to minimum conditioning period of 14 days with top, bottom and two opposite side faces of the specimen except the two longitudinal faces covered with paraffin wax. The specimen thus after 42 days of casting, is placed in the storage chamber for minimum 70 days at CO<sub>2</sub> levels of (4.0±0.5)%, temperature of (20 ± 2)°C and relative humidity of (55±5)%. Then the specimen is split into half and taken for measurement of carbonation depth after spraying phenolphthalein indicator on the cut surfaces. Figure 2 shows typical photos of carbonation studies done at university of Bath, UK on the concrete specimens with and without plastic waste.



(a)



(b)

Figure 2 Accelerated Carbonation levels in concrete with (a) no plastics (b) 10% plastic replacement

### Scanning Electron Microscope studies

Figure 3 (a) shows the Scanning Electron Microscope (SEM) used in the studies at University of Bath, UK and Figure 3 (b) shows the specimen used in the studies. The SEM studies will be conducted on the concrete specimen with varying percentage of plastic waste from 0%, 5%, 10% and 20% by volume of fine aggregates.



(a)



(b)

Figure 3 (a) Scanning Electron Microscope (b) Concrete specimen used at University of Bath

### Fire Testing

The comparative performance of various mixes of concrete with plastic as partial replacement for sand will be determined using a standard fire test. Concrete samples in the form of cubes of size 100mm and cylinders of 100mm diameter will cast with varying percentage of plastic waste from 0%, 5%, 10% and 20% and cured for one month before being subjected to an ISO 834 standard fire curve for 120 minutes. The peak temperature in the test will be approximately 1050°C. The cubes will then be tested in compression and the cylinders will be tested in split cylinder test.



## CONCLUDING REMARKS

From the above study it can be concluded that post-consumer products and industrial waste products/by-products can be successfully used in concrete to replace coarse or fine aggregates. However, there is decrease in workability and compressive strength of the concrete resulting in the concrete so produced not to be used for structural purposes. However, the structural properties need to be enhanced by using suitable chemical/mineral admixtures. The accelerated carbonation studies to understand the durability of concrete produced with plastic waste, scanning electron microscopy to understand the concrete matrix and pores created due to plastic waste in concrete mix and the fire resistance tests are the most important tests which need to be performed to understand the behaviour of structural concrete produced with plastic waste.

## ACKNOWLEDGMENTS

The data presented in this paper is from the research work in progress in the project sanctioned by the British Council to Government Polytechnic, Bicholim – Goa and University of Bath, UK under the scheme United Kingdom India Education Research Initiatives (UKIERI) for the period from 2014-16. The Authors thankfully acknowledges the funding by Council for carrying out the research work (UKIERI-ICB/13-14/047).

## REFERENCES

1. <http://minerals.usgs.gov/minerals/pubs/commodity/cement/mcs-2015-cemen.pdf>
2. BANDODKAR L R, GAONKAR A A, GAONKAR N D, GAUNS Y P, ALDONKAR S S, SAVOIKAR P P, Pulverised PET bottles as partial replacement of sand. International Journal of Earth Sciences and Engineering, 2011, Vol 4, No 6 spl, pp 1009-1012.
3. FRIGIONE M, Recycling of PET bottles as fine aggregate in concrete. Waste Management, 2010, Vol 30 , pp 1101-1106.
4. MARZOUK O Y, DHEILLY R M, QUENEUDEC M, Valorization of post-consumer waste plastic in cementitious concrete composites. Waste Management, 2007, Vol 27, pp 310–318.
5. CHOI Y W, MOON D J, CHUNG J S, CHO S K, Effect of waste PET bottles aggregate on properties of concrete. Cement and Concrete Research, 2005, Vol 35, pp 776–781.
6. AKCAOZOGLU S, ATIS C D, AKCAOZOGLU K, An investigation on the use of shredded waste PET bottles as aggregate in lightweight concrete. Waste Management, 2010, Vol 30, pp 285–290.

7. ISMAIL Z Z, AL-HASHMI E A, Use of waste plastic in concrete mixture as aggregate replacement. *Waste Management*, 2008, Vol. 28, pp 2041–2047.
8. NIBUDEY R N, NAGARNAIK P B, PARBAT D K, PANDE A M, Cube and cylinder compressive strengths of waste plastic fiber reinforced Concrete. *International Journal of Civil and Structural Engineering*, 2013, Vol 4, No 2, pp 174-182.
9. Sung B K, Na Hyun Y K, Jang-Ho J K, Young-Chul S, Material and structural performance evaluation of recycled PET fiber reinforced concrete. *Cement and Concrete Composites*, 2010, Vol 32, pp 232-240.
10. DORA F, Preliminary analysis of concrete reinforced with waste bottles PET fibers. *Construction and building materials*, 2011, Vol 25, pp 1906-1915.
11. OSMANI M, PAPPU A, An Assessment of the Compressive Strength of Glass Reinforced Plastic Waste Filled Concrete for Potential Applications in Construction. *Concrete Research Letters* , 2010, Vol 1, No 1, pp 1-5.
12. RAGHVAN D, HUYNH H, FERRARIS C F, Workability, mechanical properties and chemical stability of a recycled tire rubber-filled cementitious composite. *Journal of Materials Science*, 1998, Vol 33, No 7, pp 1745–1752.
13. TOPCU I B, CANBAZ M, Properties of concrete containing waste. *Cement and Concrete Research*, 2004, Vol 34, No 2, pp 267-274.
14. TERRO M J, Properties of concrete made with recycled crushed glass at elevated temperatures. *Building and Environment*, 2006, Vol 41, No 5, pp 633-639.
15. DUCMAN V, MLADENOVIC A, SUPUT J S, Lightweight aggregates based on waste glass and its alkali-silica reactivity. *Cement and Concrete Research*, 2002, Vol 31, No 2, pp 223-226.
16. KHATIB Z K, BAYOMY F M, Rubberized Portland cement concrete. *ASCE Journal of Materials in Civil Engineering*, 1999, Vol 11, No 3, pp 206–213.
17. ALBANO C, CAMACHO N, REYES J, FELIU J L, HERNANDEZ M, Influence of scrap rubber addition to Portland Concrete Composites: Destructive and non-destructive testing. *Composite Structures*, 2005, Vol 71, pp 439–446.
18. LOPES LIMA, P R, LEITE M B, RIBEIRO SANTIAGO E Q, Recycled lightweight concrete made from footwear industry waste and CDW. *Waste Management*, 2010, Vol 30, pp 1107–1113.
19. NAIK T R, SINGH S S, THARANIYIL M P, WENDORF R B, Application of foundry by-product materials in manufacture of concrete and masonry products. *American Concrete Institute Materials Journal*, 1996, Vol 93, No 1, pp 41-50.
20. NAIK T R, PATEL V M, PARIKH D M, THARANIYIL M P, Utilisation of foundry sand in concrete. *ASCE Journal of Materials in Civil Engineering*, 1994, Vol 6, No 3, pp 254-263.

21. NAIK T R, WEI L H, SINGH S S, Low-cost-ash-derived construction materials: State – of-the-art assessment. EPRI Report No. TR-100563, 1992, Palo Alto, CA.
22. WEI L H, Utilisation of coal combustion by-products for masonry construction. EPRI Report No. TR-100707, 1992, Palo Alto, CA.